Monitoring of gut mucosal perfusion is of established clinical interest. There are many methods available to aid the clinician in the diagnosis and monitoring of gut mucosal ischaemia but few are of practical use in the clinical domain. The only clinical monitor currently available that can provide such information and is practical for use during routine practice is the gastrointestinal tonometer.

Tonometry refers to measurement of partial pressure of a gas. Gastrointestinal tonometry uses a modified nasogastric tube to allow measurement of carbon dioxide tension in the lumen of the gastrointestinal tract. This measurement, when used in combination with arterial bicarbonate, can be used to estimate the intramucosal pH (pHi) of the gastrointestinal tract. Despite several fundamental flaws in the tonometric technique, experimental studies have shown that mucosal acidosis (measured with the gastrointestinal tonometer) correlates with reduced mucosal perfusion and/or the onset of anaerobic metabolism in response to hypovolaemia, hypoxaemia and sepsis.

The clinical use of gastrointestinal tonometry remains controversial, despite an impressive clinical research record. In many, although not all, published studies of patients admitted to adult intensive care units, an abnormally low pHi value has been found to be common and associated with a poor outcome. In a prospective, randomized, multicentre study of pHiguided therapy, a >25% improvement in survival was reported in patients admitted to the ICU with a normal pHi. Numerous published studies on hundreds of patients have examined the relationship between pHi and outcome after accidental trauma or major surgery and have concluded that the presence of a low pHi is a predictor of poor outcome. In studies that compared tonometry with other routinely used monitors of cardiorespiratory function, it has been found to be a more sensitive predictor of morbidity than global measures such as arterial pressure, cardiac output or urine flow measurement. In a prospective, randomized study of trauma patients, Ivatury and colleagues compared PA catheter oxygen delivery-oxygen consumption-guided therapy with pHiguided therapy. They found that patients who corrected their pH by 24 h had a better outcome, irrespective of the treatment group, and there was a marked trend towards improved outcome in the pHiguided group. We have reported the results of a prospective, randomized study of the effects of fluid loading patients undergoing elective cardiac surgery with the aim of maintaining perioperative gastric mucosal perfusion. We found that the incidence of a low pHi was significantly reduced in the study group compared with controls, as were the number of major complications and days spent in hospital. Marik, Iglesias and Maini reported similar findings in patients undergoing aortic surgery with regards to pHi but not outcome. In both studies, pHi was used as an outcome variable but not as a monitor to guide therapy.

A monitor is a warning device that detects a physiological abnormality allowing the physician to intervene to correct the abnormality with the hope that it is associated with an improvement in outcome. Aside from the concerns surrounding the whole concept of gastrointestinal tonometry and whether or not it can be used as a measure of tissue perfusion-oxygenation, there are major concerns about the practicalities of the established saline catheter technique. First, the numerous steps involved mean that it is prone to many systematic errors. Second, as highlighted by Kolkman and colleagues in this issue of the journal, equilibration of carbon dioxide with saline within the tonometer balloon is never complete and thus a time-dependent correction factor is required. Third, routinely used blood-gas analysers are not well designed for measurement of carbon dioxide in saline, and bias and imprecision are common. Fourth, the fact that it is a manual system with a long equilibration period makes it virtually impossible to use as a true monitor in the setting of acute resuscitation (e.g. during major surgery).

The introduction of the Tonocap (Instrumentarium Corp., Helsinki, Finland) is an important advance. The Tonocap is designed to use the same TRIP tonometer catheters (Instrumentarium Corp., Helsinki, Finland) that were used for saline tonometry. The device inflates the balloon on the end of the catheter with a small volume of air, allows for equilibration with the gastrointestinal environment, then automatically aspirates the balloon content. The gas from the balloon is analysed using the same infra-red method used to measure expired gas mixtures. The sample is then replaced into the balloon to decrease the equilibration time for the next.

We have seen reports previously of in vitro testing, suggesting many of the systematic errors involved in balloon saline tonometry and concerns about equilibration times have been eliminated. The Tonocap has minimal bias and excellent precision for determination of $P_{CO_2}$ in vitro. As with any monitoring device, in vivo use is associated with a reduction in precision. One of the difficulties in determining performance in patients is the lack of a gold standard for measurement of tissue $P_{CO_2}$. Therefore, when saline tonometry is used as a gold standard we should not be surprised to see a large scatter, as reported in the study of Janssens and colleagues in this issue of the journal. In vitro testing has shown that the saline method has a fixed negative bias and a much higher degree of imprecision.

The fact that the Tonocap combines both end-tidal and gastrointestinal luminal carbon dioxide measurement could mean that arterial blood-gas analysis will no longer be an essential component of gastrointestinal tonometry. The calculated pHig concept is already unpopular as it is influenced markedly by acid-base disturbances that may be independent of gut perfusion. Gastrointestinal $P_{CO_2}$ is uninterpretable without reference to arterial carbon dioxide, as both are directly influenced by alveolar ventilation.
This has led to the popularization of the “CO₂ gap” (i.e. gastrointestinal $p_{CO_2}$–arterial $p_{CO_2}$). However, calculation of the CO₂ gap demands arterial blood-gas analysis and thus reduces the value of automated online tonometry measurements: it is unlikely that blood-gas analysis is performed every 10 min. The automated calculation of the gastrointestinal–end-tidal $p_{CO_2}$ gap could overcome all of these issues. At first glance, an obvious source of error lies in the well recognized gradient between end-tidal and arterial carbon dioxide and the influence of ventilation–perfusion mismatching on physiological deadspace. On more careful consideration, these may not be real problems in clinical practice. First, all monitors are most useful as trend indicators providing there is confidence in the quality of signal—we already accept this limitation with routine use of end-tidal $p_{CO_2}$ measurement. Second, any increase in physiological deadspace secondary to reduced pulmonary perfusion tends to exaggerate the gap between end-tidal and gastrointestinal $p_{CO_2}$ rather than reduce it. This may expose some patients to unnecessary treatment but will not leave patients with dangerously covert gut mucosal hypoperfusion.

There are several issues that need careful consideration before we accept the Tonocap as a direct substitute for saline tonometry: (i) the Tonocap has eliminated negative bias associated with the saline measurement, thus direct comparisons with saline data are of limited value; (ii) the Tonocap and in particular gastrointestinal–end-tidal $p_{CO_2}$ needs independent investigation and validation; (iii) the vast majority of the previously published tonometry data were collected using the saline method and calculation of pHᵢ. A leap of faith to “CO₂ gap” means the metabolic component from arterial bicarbonate is lost and therefore one should not necessarily assume that the predictive ability will be as high; and (iv) it is inevitable that any new monitor is associated with a list of artefacts not anticipated by the manufacturers and these will only come to light with clinical experience.

In summary, with the clinical availability of the Tonocap, gastrointestinal tonometry has come of age. If we choose to measure the $p_{CO_2}$ of a patient's gastrointestinal tract, it can be done more easily and reliably than ever before using the Tonocap. Should we bother? Well, who knows? It is a decision we have to make for ourselves. Awaiting the results of large, prospective, randomized, multicentre studies is unlikely to provide answers that will enhance our decision. There is no precedent for a physiological monitor used in anaesthetics. Traditionally, we have said if we can detect and correct a physiological abnormality (e.g. hypoxaemia and the pulse oximeter) then that is good enough. A monitor is not a therapy and as such cannot influence outcome. A monitor can only guide therapeutic intervention. Therefore, it is extremely unlikely that anyone will ever organize or fund a study that will support or refute the suggestion that the Tonocap will help you to help your patients. Sad, but true.

M. G. MYTHEN
A. R. WEBB
UCL Hospitals
Mortimer St
London WIN 8AA

References